

## Development of a Pan-Arctic Database for River Chemistry

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More than 10% of all continental runoff flows into the Arctic Ocean. This runoff is a dominant feature of the Arctic Ocean with respect to water column structure and circulation. Yet understanding of the chemical characteristics of runoff from the pan-Arctic watershed is surprisingly limited. The Pan-Arctic River Transport of Nutrients, Organic Matter, and Suspended Sediments (PARTNERS) project was initiated in 2002 to help remedy this deficit, and an extraordinary data set has emerged over the past few years as a result of the effort. This data set is publicly available through the Cooperative Arctic Data and Information Service (CADIS) of the Arctic Observing Network (AON). Details about data access are provided below.

Sampling programs were established on six rivers that account for more than half of all river discharge from the pan-Arctic watershed. Starting in western Siberia and moving eastward around the pan-Arctic domain, these rivers are the Ob', Yenisey, Lena, and Kolyma in Russia; the Yukon in Alaska; and the Mackenzie in Canada's Northwest Territories. In addition to the parameters highlighted in the PARTNERS acronym, the project also has measured many other parameters, including major ions, trace elements, and isotope ratios. While a variety of studies by PARTNERS scientists and others have focused on the chemistry of individual Arctic rivers, differences in methods and parameters measured have hampered river intercomparisons and understanding at the pan-Arctic scale. Furthermore, most previous studies of large Arctic rivers were conducted only during summer. Thus, implementation of standard protocols, including seasonally representative sampling, was a key consideration for the PARTNERS project.

The PARTNERS data set provides an essential baseline for detecting changes in the pan-Arctic watershed. The six rivers capture runoff from 10.34 million square kilometers, and thus changes in the chemistry of these rivers would indicate widespread changes in watershed processes such as permafrost

dynamics, soil weathering, and microbial activity. While elucidation of specific mechanisms behind changes in river chemistry requires direct study of potential drivers, river chemistry provides an integrative signal that helps to constrain the possible mechanisms and thereby to develop informed hypotheses in support of more focused studies. For example, an increase in the age of river-borne dissolved organic carbon would point toward mobilization of ancient organic matter from thawing permafrost. High-quality baseline data also support better informed studies of how changes in river export may influence ocean ecosystems.

One of the primary goals of PARTNERS was to improve estimates of chemical parameters used to differentiate freshwater sources in the Arctic Ocean. These parameters include the isotopic composition of hydrogen and oxygen in water molecules as well as concentrations of barium and alkalinity that have been used to track river water in the Arctic Ocean. The resolution of freshwater sources has been relatively coarse due to uncertainty in estimates of tracer values for individual rivers. The PARTNERS data constrain these estimates by capturing seasonal dynamics and by facilitating the calculation of flow-weighted averages that better represent annualized inputs.

The full PARTNERS data set includes approximately 50 parameters. Twenty-four of these parameters are shown in Figure 1, where values for high flow in each river are

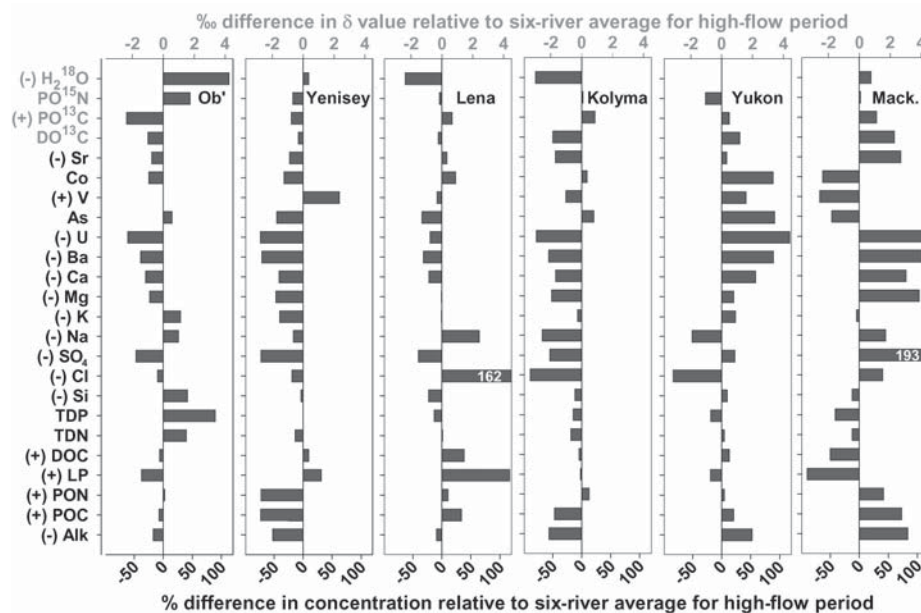


Fig. 1. Differences in chemistry among Pan-Arctic River Transport of Nutrients, Organic Matter, and Suspended Sediments (PARTNERS) rivers during high flow, late May through mid-June. Differences in isotope ratios are reported as  $\delta$  values (‰). All other differences are percentages. Plus signs in front of parameter labels indicate increases from low to high flow at all rivers, and minus signs indicate decreases from low to high flow.  $H_2^{18}O$  is the  $\delta^{18}O$  of water,  $PO^{15}N$  is the  $\delta^{15}N$  of particulate organic nitrogen (PON),  $PO^{13}C$  is the  $\delta^{13}C$  of particulate organic carbon (POC),  $DO^{13}C$  is the  $\delta^{13}C$  of dissolved organic carbon (DOC), TDP is total dissolved phosphorus, TDN is total dissolved nitrogen, Alk is total alkalinity, and LP is lignin phenols. Values for Alk, LP, strontium (Sr), cobalt (Co), vanadium (V), arsenic (As), uranium (U), barium (Ba), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), sulfate ( $SO_4^{2-}$ ), chloride ( $Cl^-$ ), and silicon (Si) are from filtered (0.45-micron) samples.

expressed relative to the average for all rivers. This representation of the data highlights major differences in chemistry between the North American and Eurasian rivers. In particular, concentrations of uranium, barium, calcium, sulfate, and total alkalinity are much higher in the North American rivers. There are also many striking differences in chemistry among rivers within each continental grouping. In contrast, seasonal patterns in chemistry are remarkably similar among rivers. This seasonality is tightly linked to hydrographic variations at all of the rivers, with individual parameters consistently showing positive or negative correlations with discharge (indicated in Figure 1 by plus or minus signs in front of parameter labels). Recent analyses of dissolved organic carbon export from rivers to the Arctic Ocean using PARTNERS data, including revised estimates of export quantity, age, and losses within the Arctic Ocean, are given by Cooper *et al.* [2005] and Raymond *et al.* [2007].

Sampling was conducted at Salekhard (Ob'), Dudinka (Yenisey), Zhigansk (Lena), Cherskii (Kolyma), Pilot Station (Yukon), and Tsiigehtchic (Mackenzie). These sites are located far down on each river and thus capture flow contributions from the vast majority of each river's watershed. PARTNERS participants completed 17 sampling trips on each river between summer 2003 and fall 2006. The trips were distributed in time to capture low flow during late winter (under ice), high flow during spring melt, and intermediate flow during summer/fall. Protocols were established using U.S. Geological Survey (USGS) guidelines, including the use of depth/flow integrating samplers. PARTNERS sampling on the Yukon was coupled with USGS work ongoing since 2001.

Funding for the PARTNERS project ended in fall 2007, but sampling will continue at the sites established during PARTNERS, at least through 2011, as a component of the developing AON. Within this network, the river sampling program is now identified as the Arctic Great Rivers Observatory (Arctic-GRO). The Arctic-GRO is being maintained by a subset of the PARTNERS participants, with Bruce Peterson as the lead scientist. The importance of the AON is underscored by observations of widespread changes in the Arctic during recent years [Symon *et al.*, 2005]. Many changes in the Arctic are coupled to the freshwater cycle and have feedbacks to global climate [White *et al.*, 2007].

Routine data for the Yukon River at Pilot Station are available at <http://nwis.waterdata.usgs.gov/ak/nwis>. All other PARTNERS data, including nonroutine data for the Yukon, are available on the CADIS Web site, under the Arctic-GRO heading (<http://www.eol.ucar.edu/projects/aon-cadis/>).

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## From Corals to Canyons: The Great Barrier Reef Margin

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The significance of submerged fossil coral reefs as important archives of abrupt global sea level rise and climate change has been confirmed by investigations in the Caribbean [Fairbanks, 1989] and the Indo-Pacific (see Montaggioni [2005] for a summary) and by recent Integrated Ocean Drilling Program (IODP) activities in Tahiti [Camoin *et al.*, 2007]. Similar submerged (40–130 meters) reef structures are preserved along the margin of the Great Barrier Reef (GBR), but they have not yet been systematically studied.

The submerged reefs have the potential to provide critical new information about the nature of past global sea level and climate variability and about the response of the GBR to these past and perhaps future environmental changes [Beaman *et al.*, 2008]. Equally important for GBR Marine

Park managers is information about the role of the reefs as habitats and substrates for modern biological communities.

Here we summarize the highlights and broader implications of a September–October 2007 expedition on the R/V *Southern Surveyor* (Australian Marine National Facility, voyage SS07/2007) to investigate the shelf edge, upper slope, and submarine canyons along the GBR margin.

#### GBR Fossil Reefs

The multibeam, seismic, and autonomous underwater vehicle (AUV) imagery provides a comprehensive view of the morphology and spatial distribution of the fossil reefs and terraces along the shelf edge between 40 and 130 meters (Figure 1). The shelf edge is where the GBR has spent about 85% of its time over the past approximately 500,000 years as climate varied and sea

level fluctuated back and forth across the shelf edge.

The new data reveal a diverse suite of surface and subsurface features that includes submarine terraces, complex relict fringing, barrier, patch reef, and lagoonal systems, along with paleoriver channels and relict dune systems. An example survey area near Cairns (Figure 1 inset) illustrates the high quality of the imagery and shows the relationship between a paleoriver channel system and the fossil reefs at the shelf edge. These features likely reflect a complex history of growth and erosion during periods of sea level change at lower sea levels relative to today. Preliminary observations of rock dredge samples suggest that the relict reef features may be capped by coral reef material deposited during the last deglaciation (20,000–10,000 years ago).

#### Deep Benthic Habitats

Little is known about the modern benthic communities associated with the shelf edge reefs, despite their widespread occurrence throughout the Great Barrier Reef World Heritage Area (GBR/WHA). The new AUV